AFRL-SR-AR-TR-02-

0237

REPORT DOCUMENTATION PAGE

1. REPORT DATE *(DD-MM-YYYY)* 28-06-02	**2. REPORT TYPE** Final Technical Report	**3. DATES COVERED** *(From - To)* From 01-03-01 to 28-02-02

4. TITLE AND SUBTITLE

Reactions of Energetic Ions with Thin Film Surfaces

5a. CONTRACT NUMBER

5b. GRANT NUMBER
F49620-01-1-0203

5c. PROGRAM ELEMENT NUMBER
61103D

5d. PROJECT NUMBER
3484

5e. TASK NUMBER
US

5f. WORK UNIT NUMBER

6. AUTHOR(S)

Dennis C. Jacobs

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Notre Dame
511 Main Building
Notre Dame, IN 46556

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AFOSR/NL
801 N. Randolph St., Rm. 732
Arlington, VA 22203-1977

10. SPONSOR/MONITOR'S ACRONYM(S)
AFOSR/NL

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES

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14. ABSTRACT

The PI has designed and constructed a multifunction vacuum chamber for evaporating metal films and depositing insulating layers. The chamber is to be used for fabricating metal-insulator-metal (M-I-M) devices that function as novel solid-state electron emitters. Nanoscale M-I-M devices deliver hot electrons to the metal/vacuum interface from within the solid. These hot electrons can stimulate nonthermal chemical reactions at the gas/surface interface or supplement the charge density of a plasma above the device.

The chamber houses an electron analyzer for testing the devices *in situ*. Moreover a load-lock permits easy introduction of samples and transference to an adjoining ultrahigh vacuum (UHV) chamber so that more detailed surface analyses can be performed.

15. SUBJECT TERMS

Deposition, Thin-films, Nanofabrication

16. SECURITY CLASSIFICATION OF: Unclassified			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Dennis C. Jacobs
Unclassified	Unclassified	Unclassified	UL	9	**19b. TELEPHONE NUMBER** *(include area code)* (574)631-8023

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

20020816 063

UNIVERSITY OF
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Department of Chemistry and Biochemistry
University of Notre Dame
Notre Dame, IN 46556

Air Force Office of Scientific Research
Molecular Dynamics Program
Program Officer: Michael R. Berman
Grant # F49620-01-1-0203
Final Technical Report
1 March 2001 – 28 February 2002

Reactions of Energetic Ions with Thin Film Surfaces

Dennis C. Jacobs, Ph.D.
Principal Investigator

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Executive Summary

A deposition chamber has been designed and constructed to fabricate and test metal-insulator-metal (M-I-M) devices. This equipment directly supports the work of AFOSR Grant F49620-01-1-0412, a THEMES project entitled "Dynamics of Plasma-Surface Interactions." M-I-M devices are being developed as a novel way to eject hot electrons into the weakly ionized plasma surrounding a hypersonic vehicle. These solid-state cold-cathode emitters may also induce non-thermal surface chemistry at the metal/vacuum interface.

The new apparatus contains a magnetron sputter deposition source, a five-pocket metal evaporation source, a two-stage deposition chamber, and the necessary pumps, valves, and electronics. The chamber design is flexible to allow for rapid access to the sample through a load-lock, deposition of virtually any metal or insulating material, a computer-interfaced mask for precise patterning on the sample, and an *in situ* electron detector. The fabrication strategy involves producing multiple M-I-M devices on a single substrate. This will allow for rapid screening of M-I-M designs to optimize the fabrication conditions for maximal device performance.

1. Introduction

The development of many advanced technologies for hypersonic transport (e.g., drag reduction, electromagnetic cloaking, combustion enhancement, and magneto gas dynamic control) relies on a weakly ionized plasma flow around the vehicle.[1,2] A potential strategy for augmenting the plasma density surrounding hypersonic vehicles involves encasing the surface of the vehicle with functioning Metal-Insulator-Metal (M-I-M) devices. These novel solid-state devices act as cold-cathode emitters, ejecting electrons into the vacuum.[3]

This DURIP grant was used to purchase equipment for fabricating and testing M-I-M devices in a highly controlled environment. Thin films (10 - 100 nm thick) of conducting and insulating materials are layered on a silica support. The optimal M-I-M performance depends critically on the composition and thickness of the heterostructure.[4,5]

2. Apparatus Design

The design of the new deposition chamber is shown in Fig. 1. It features a load lock for rapidly introducing samples into the system. At the far left of the chamber is a manipulator that translates the sample along a guide tube. All electrical feedthroughs make contact with the sample through wires running down the bore of the guide tube. The left chamber allows for the deposition of insulating materials using a magnetron-sputtering source. The plasma is contained within a stainless steel sheath to reduce contamination in the chamber. The left chamber is pumped with a turbomolecular pump to permit oil-free vacuum with fast pumpdown times.

The left and right chambers are separated by a pneumatic gate valve. The right chamber is independently pumped by a cryopump. The right chamber is used for evaporating metals from an electron gun evaporation source. The e-gun heating system

provides very efficient evaporation of metals (e.g., Ag, Au, Cu, and Al) at rates approaching 1500 Å per minute. A computer-controlled mask situated between the evaporation source and the substrate allows for precise patterning of metal layers in the fabrication of MIM devices. In both sputter deposition and metal evaporation modes, quartz microbalance detectors provide absolute calibration of the film thickness. The right half of the chamber also contains some simple diagnostics for testing the MIM devices. These include a Faraday cup collector and a retarding field energy analyzer for measuring the emitted electron current and energy distribution, respectively.

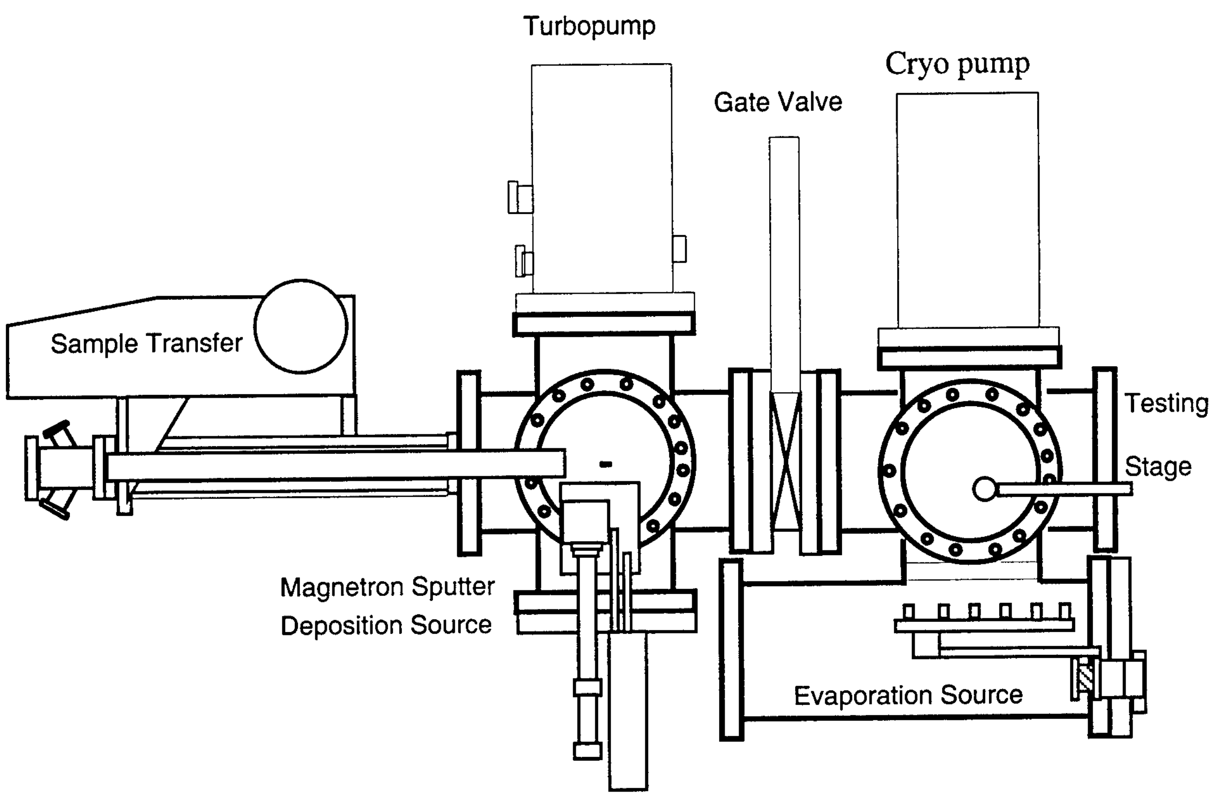

Figure 1. Schematic diagram of new deposition chamber.

3. M-I-M Design

The basic design of the M-I-M device is shown in Fig. 2. A bias between the upper and lower metal layers will cause substrate electrons to tunnel across the conduction band of the insultator and ballistically travel to the metal/vacuum interface.[6] The bias potential tunes the energy of the ballistic electrons from the Fermi level to well above the vacuum level.

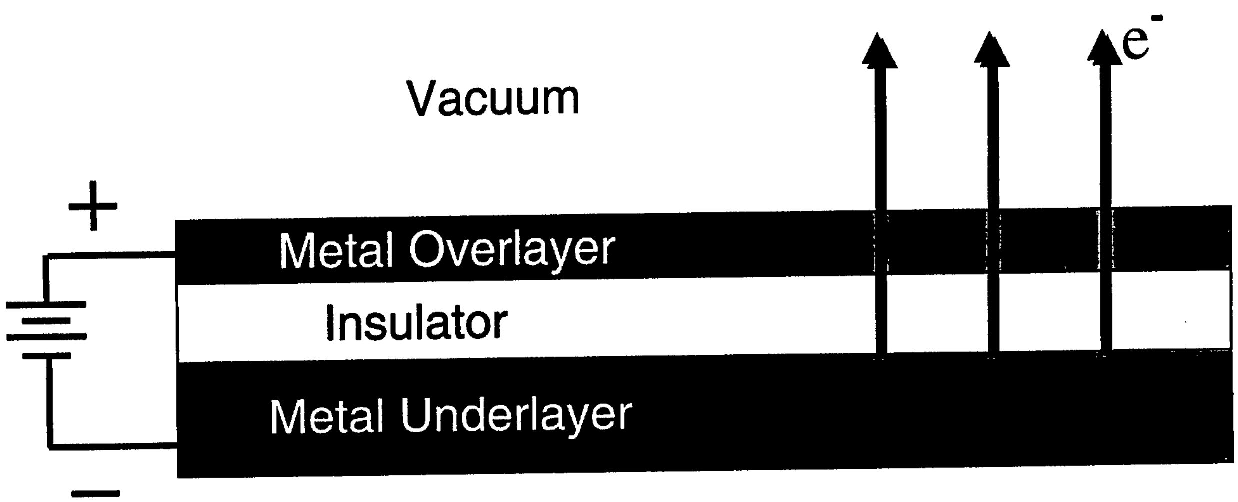

Figure 2. Electrons are emitted from the M-I-M device when the overlayer is biased positive relative to the underlayer.

The performance of the M-I-M is dependent on the composition and thickness of both the metal and insulating layers.[7] To streamline the processs of identifying optimal fabrication conditions for electron emission and longevity, we have adopted a combinatorial design approach. Figure 3 shows how multiple M-I-M devices can be fabricated on a single substrate. Each device can be fabricated differently to have it's own unique set of properties; consequently, each device must be tested individually. The electrodes can be biased in combinations to activate only one M-I-M device at a time.

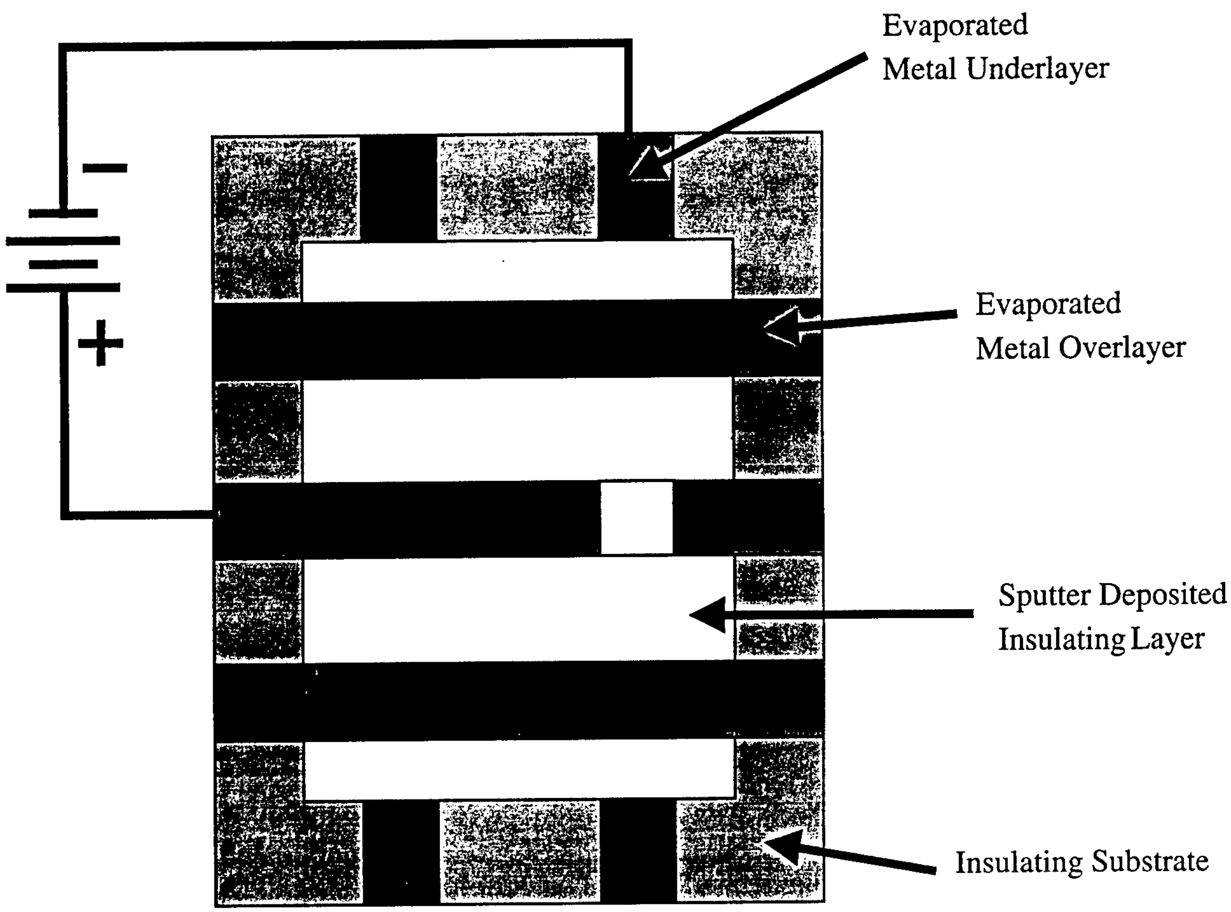

Figure 3. Combinatorial design, in the fabrication of six M-I-M devices on a single substrate, allows for rapid testing of different layer thicknesses and compositions. The illustration shows how a particular M-I-M element (shaded white) can be tested separately from the others.

Preliminary tests were performed on a metal-insulator-semiconductor (M-I-S) device fabricated on campus. A 10 nm Au film was evaporated onto a 45 nm SiO_2 layer which in turn was grown on a n-doped Si(001) substrate. Figure 4 shows how the electron emission from the device increased by six orders of magnitude as the bias potential was ramped from 8 to 15 V. This nonlinear behavior underscores the nonclassical nature of the tunneling phenomonon associated with M-I-M and M-I-S technology.[8]

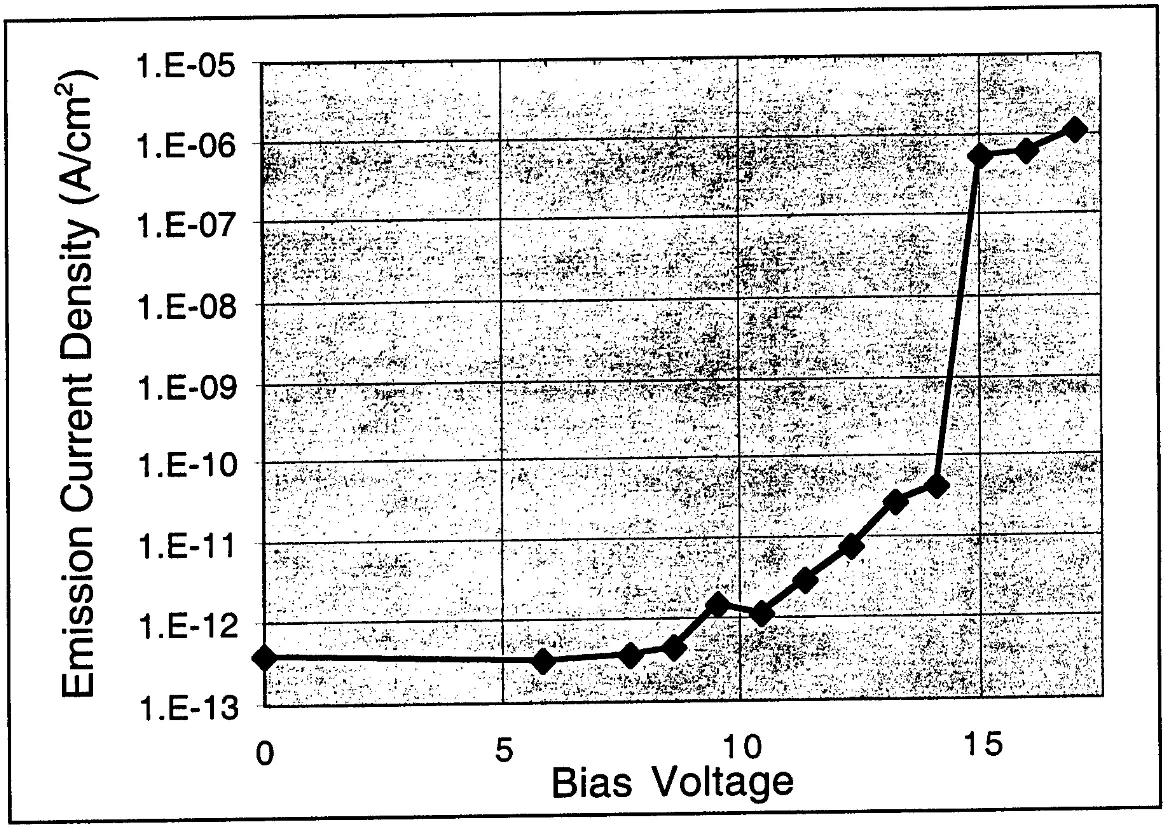

Figure 4. The emission current density of a metal-insulator-semiconductor (M-I-S) device as a function of the bias potential applied across the two electrodes.

4. Conclusion

The versatility of the new apparatus allows us to deposit virtually any combination of metal and insulating layers with great precision. This capability is being harnessed to fabricate M-I-M devices with optimal electron-emission characteristics. Experiments will also explore the extent to which the hot electrons can induce non-thermal chemistry at the gas/solid interface. These nanolaminate materials hold promise as a cold-cathode source for seeding the plasma surrounding a hypersonic vehicle.

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